

THE SOLID STATE DETECTOR TECHNOLOGY FOR PICOSECOND LASER RANGING

I. Procházka

Faculty of Nuclear Science and Physical Engineering, Czech Technical University
Brehova 7, 115 19 Prague, 1 Czechoslovakia
phone/fax +42 2 848840, telex 121254 fjfi c, E-mail tjean@csearn.bitnet

GENERAL

The millimeter accuracy, multiple wavelength laser ranging to the satellite and long ground baseline is a goal for nineties. Assuming the laser, optics and electronics technology currently available, the optical detectors represent the principal contributions to the ranging error budget in the laser ranging chain. In our group we developed an all solid state laser ranging detector technology [1,2,3], which makes the goal of millimeter accuracy achievable. Our design and construction philosophy is to combine the techniques of : single photon ranging, ultrashort laser pulses and fast fixed threshold discrimination while avoiding any analog signal processing within the laser ranging chain.

The all solid state laser ranging detector package consists of the START detector and the STOP solid state photon counting module. Both the detectors are working in an optically triggered avalanche switching regime. The optical signal is triggering an avalanche current buildup which results in the generation of an uniform, fast risetime output pulse. The fixed threshold discrimination represents no drawback for our application. In connection with the ultrashort laser pulses (35 picoseconds or less), this detection technique introduces the timing jitter of a few picoseconds on the multi photon signal level and less than 15 picoseconds on a single photon signal level. Omitting the fast analog signal processing is simplifying the ranging system and simultaneously increasing its temporal stability.

START DETECTOR PACKAGE

It detects a small portion of the laser output and triggers the time interval unit. The detection structure on silicon is used. The detector is operating in an avalanche switching regime, it is acting as a fixed threshold opto switch generating on its output an uniform current pulse. Its amplitude is typically 8 Volts, length 5 nanoseconds, the risetime is bellow 400 picoseconds. Thanks to the output pulse shape and its uniformity, no additional pulse amplification and discrimination is needed. As no analog signals are propagating along the cables, the detector output is uniform and its amplitude is high, the whole setup is highly resistant to the radio frequency interference and electrical noise problems. This fact is becoming significant in the vicinity of a laser system generating a lot of electrical noise. The detector is capable of operation in three modes :

1. In linear mode it may be used as a laser output pulse monitor with the bandwidth of 1 GHz.

In this mode, the optical alignment of the detector may be optimized.

2. The **opto switching mode** described above is used for ranging.

3. In the **self oscillation mode** the detector generates on its output the sequence of uniform output pulses with the repetition rate of about 1 kHz. This mode is an attractive feature for test purpose.

The detector jitter contribution to the overall jitter budget was not measured independently. When it has been used to trigger the streak camera, the overall trigger jitter (detector + streak camera) of 8-16 picoseconds has been observed using the passively mode locked lasers with pulse length 3 - 100 psec FWHM. Thus, the trigger jitter contribution of the START detector itself is well below 15 picoseconds for these pulse lengths. Generally, in connection with the active-passive mode locked lasers with pulse lengths below 100 psec and the fast response time interval unit input, the jitter contribution of the START detector may be neglected.

SOLID STATE PHOTON COUNTING MODULE

It is used to detect the laser ranging echo signals. The Module is a self consistent detector package, which detects single photons of light over the wavelength range from 0.35 to 1.1 microns. The Module utilizes a unique silicon Single Photon Avalanche Diode (SPAD) [4,2], which is connected in the active quenching and gating circuit and pulse biased above the break. Biasing the diode above the break, the extreme gain of order of $1 \cdot 10^9$ is achieved. This high gain obtained within the semiconductor chip permits to avoid any further amplification of the detector output and the constant fraction discrimination, as well. Simple fixed threshold discrimination technique is used to recognize the detector output and to generate the uniform output NIM pulse. The detector may be gated using the TTL signal, the 'gate on' delay is below 25 nanoseconds. The detection diode together with the active quenching circuit, the gating logic, the discriminator, output pulse forming circuit and the light collecting optics is enclosed in one package. It is a cylinder, 120 millimeters long, 40 millimeters in diameter. The optics has an effective focal length 10 millimeters and is optimized for the beam diameter of 8-10 millimeters. Due to the diode relatively small sensitive area (20, 40 or 100 micrometers), the resulting receiver field of view is limited. Using the 100 micrometer diameter diode and the final collecting optics $f/D=1$, the resulting field of view is 40 arc seconds when installed in the 0.5 meter input aperture telescope. Using the same diode in connection with the 1 meter aperture telescope, the 20 arc seconds field of view is achieved. The 40 μm detection chip has been successfully used for SLR at Helwan and Graz, however, the field of view has been too narrow for routine operation. Due to the detection and avalanche buildup mechanisms inside the SPAD chip, the minimal

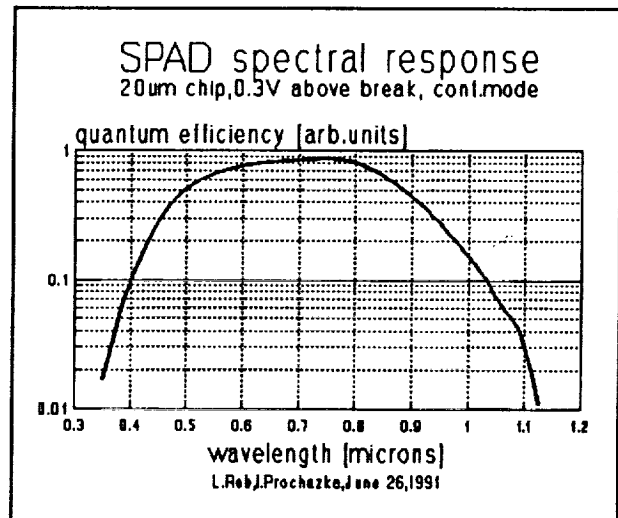


Figure 1 The SPAD relative photon detection probability, 0.3V above the break, + 25°C

detection jitter is achievable when the input photons are focussed on a small spot near to the diode's center. Thus, the good quality light collecting and beam focussing optics together with a careful optical alignment is essential for minimal jitter.

The photon detection probability and its dependence on the wavelength has been measured using the 20 μm diameter diode operating in the continuous counting mode. The diode was biased 0.3 Volt above the break. The results are plotted on Figure 1. The detection probability depends on the diode biasing, it increases with the increase of the bias up to 3 Volts above the break. For higher biases, the photon detection probability is not increasing more. The absolute figures of the quantum efficiency have been estimated by comparison to the calibrated photocathode to be 20 % at 0.53 μm wavelength and bias 3 Volts above the break. Using the calibrated light source and filters, the quantum efficiency exceeding 20 % at 0.8 μm wavelength and biased only 1V above the break has been observed [5].

DETECTORS PERFORMANCE

Since the last Workshop presentation [6], the detectors overall performance has been improved. The SPAD manufacturing technology has been tuned to get lower dark count rates. This is permitting to apply higher voltages above the break and hence to get lower jitter, lower time walk and higher photon detection probability, as well. The active quenching and gating logic has been modified (Prochazka, Kirchner) for this purpose. Cooling the diode using the Peltiere elements down to -25 Centigrades [7] the reduction of the dark count rate is achieved. This proved to be useful for ranging to low satellites suffering of the poor range prediction. Both the detectors are routinely used at the Satellite Laser Station in Graz, Austria since 1989. Most of the application results are based on the data acquired at this site.

The SPAD detector timing jitter and its dependence on the diode biasing is plotted on Figure 2. The jitter values have been computed on the basis of the ground target ranging at the 0.53 μm wavelength. At the same figure, the effective dark count rate at the temperatures +25 and -10 Centigrades is plotted. The jitter is depending on the wavelength, it is slightly increasing toward longer wavelengths and reaches 60-70 picoseconds at the 1.06 μm when the SPAD is biased 2.5V above the break. The detector package time walk, the detection delay dependence on the signal strength is plotted on Figure 3. The data have been acquired biasing the diode 2.5 Volts above the break and using the semiconductor laser pulser 32 psec FWHM. On Figure 4 there is a plot of evolution of the ranging system single shot precision using the all solid state detector technology together with the list of main upgrades. The ranging system temporal stability is demonstrated on Figure 5, where is a plot of the mean values of ground target calibration runs. It is worth to mention, that this test has been made at the time, when the system single shot precision was 8-9 millimeters. The drift of the 5 picoseconds per hour may be attributed to the

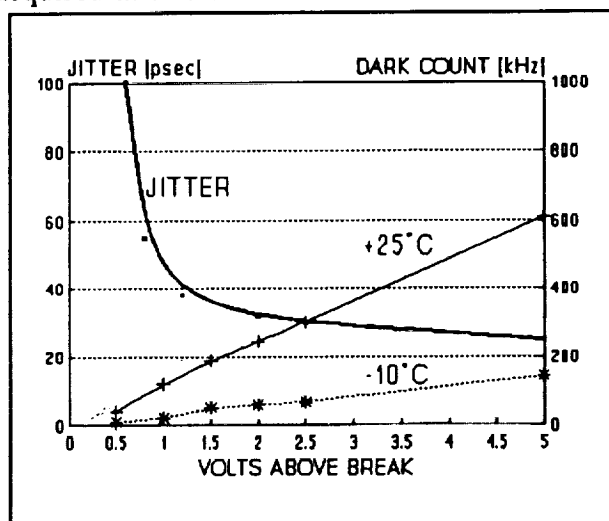


Figure 2 SPAD detector package jitter and effective dark count rate at +25°C and -10°C

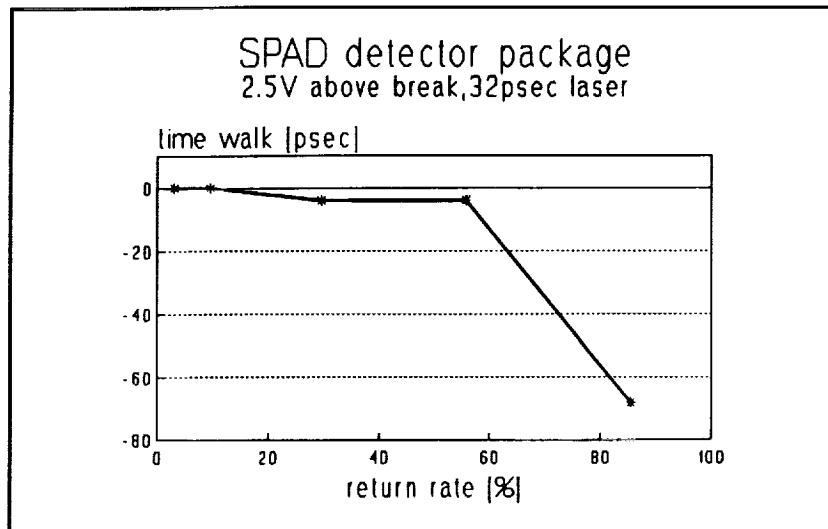


Figure 3 SPAD time walk test, 2.5V above break, 32 psec laser

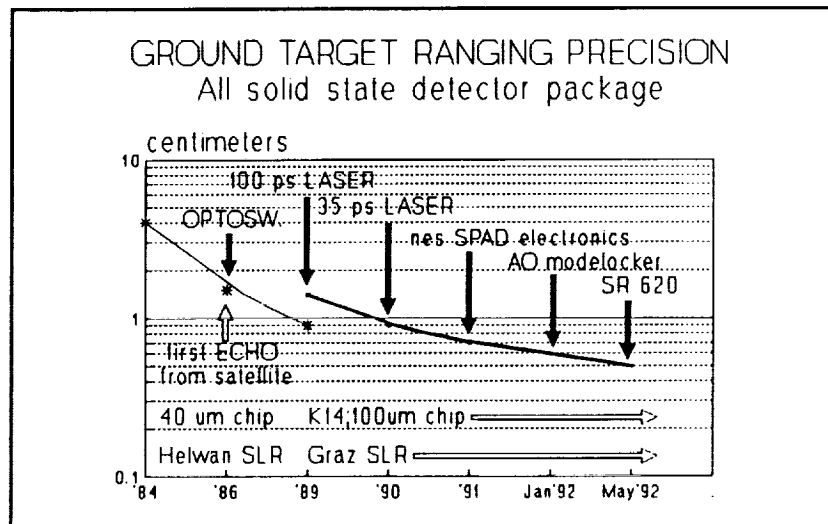


Figure 4 Ground target ranging precision increase

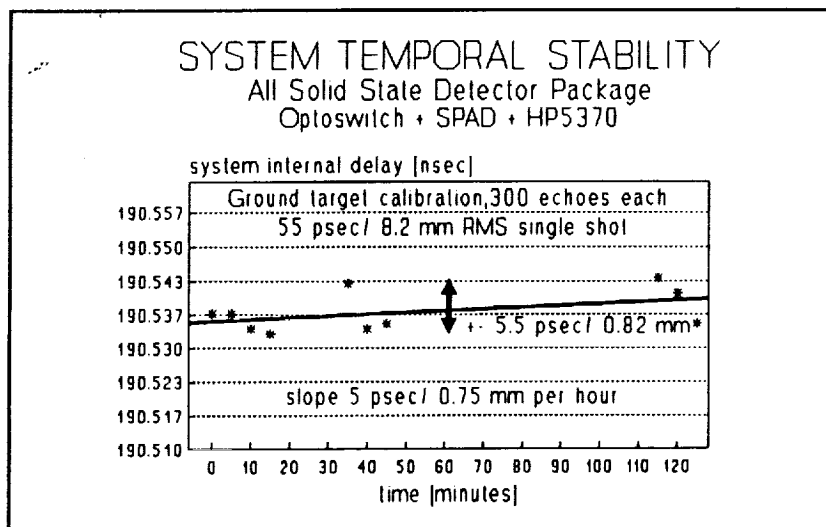


Figure 5 System temporal stability, vert. scale 1mm / div

temperature changes within the control & electronics room and its influence on the ranging counter.

SATELLITE RANGING RESULTS

The all solid state detector package has been used for routine satellite laser ranging since early 1989. Since that time, the ranging precision has been improved from original 2 centimeters to subcentimeter level in 1992.

The satellite signature - its contribution to the echo signal time spread is becoming dominant in the ranging error budget when using the 35 psec laser pulse and single photon detection. On a single photon echo signal level, the ranging precision is limited to 1.5 cm when ranging to Starlette, to 2 cm for Lageos and to 4-5 cm when ranging to Etalon satellites. The effect of the "satellite depth" may be reduced by the use of multiphoton (1-10) return signal strength. In this case, the return photon(s) reflected from the first corner cube is detected. As the detector response time is below 20 picoseconds, the photons reflected by the more distant corner cubes are not contributing and are not affecting the detection and discrimination process. Due to this effect, the satellites may be ranged with the return rate exceeding 95% without a detectable time walk and the satellite signature effect on the ranging jitter reduced.

The typical ranging precision obtained in Graz is 8 millimeters for Starlette and ERS-1 satellites, 10 millimeters for Lageos and 12-15 millimeters for Ajisai satellites.

CONCLUSION

The field use of the solid state detector package for satellite laser ranging at various sites over the world : Graz Austria, RGO Great Britain, Shanghai China, MTLRS-1 Germany proved the top performance of the solid state detector technology. The extremely simple, compact and rugged design, the absence of the analog signal processing and the resulting subcentimeter ranging capability and submillimeter temporal stability are the most attractive features. The optical alignment of the SPAD is a difficult task, but it may be solved once the receiver optics is properly designed. The satellite signature and its influence on both the random and systematic error budget is becoming significant from the point of view of millimeter ranging goal.

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